SOLAR WIND DIAGNOSTIC USING OBSERVATIONS OF INTERPLANETARY SCINTILLATIONS OF COSMIC RADIO SOURCES AT EXTREMELY LOW FREQUENCIES

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Abstract

A technique using scintillations of cosmic radio sources in the decameter waveband that allows effectively to investigate the plasma of the outer heliosphere is discussed. Results of test experiments are also adduced.

1 Ground–based IPS observations at extremely low frequencies

Despite intensive development of spacecraft methods interplanetary plasma sounding by using radiation of compact radio sources is one of the most effective ways of Solar wind research. Moreover, owing to rather large number of radio sources in the sky, the method allows to carry out global observations and to build a whole–sky picture of interplanetary plasma distribution, which has advantages over a local measurement given by a spacecraft (or few spacecrafts). Such observations are very useful both for radio waves scattering theory and for determining Solar wind shock waves associated with high–speed streams and coronal mass ejections (CMEs) in the inner and in the outer heliosphere. It is well known that influence on signal of turbulent medium increases with the wavelength, so it seemed natural to extend such observations to low frequencies.

In the eighties observations of interplanetary scintillations (IPS) of cosmic radio sources at decameter wavelengths were first carried out in the Institute of Radio Astronomy (Ukraine) by the world largest decameter radio telescope UTR–2 [Bovkoon and Zhouck, 1981]. Now new wide–band receiving equipment, high speed digital registration equipment, interference monitoring equipment and spectral data analysis method and model fitting method have been specially devised by our group in the last years to allow a qualitatively higher level to solve the problem of decameter radio waves scattering in the interplanetary medium, including small elongations.

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2 Wide–band multi–channel radio receiver for IPS observations

It is known that a scintillation spectrum is a main characteristic of radio waves scattering due to irregularities in the Solar wind. Its width is maximal at decameter wavelengths due to spectrum spreading with wavelength increasing, so it is necessary to carry out IPS observations with a short time constant of 10–100 ms. On the other hand, to observe scintillations we have to use radio sources with small angular size (such as quasars), where the maximum flux density is several hundreds Jy at decameter wavelengths. A simple calculation shows: If we would like to have a signal to noise ratio of 10, we have to use a receiver with a bandwidth of 1 MHz. Unfortunately, impulsive interference from man–made sources makes wide–band observations very hard at frequencies lower than 20 MHz, so it is desirable to work at frequencies of 20–30 MHz or higher. The IPS technique requires the possibility to work in multi–beam mode in order to take ionospheric refraction into account and to subtract noise from experimental data. It is also important to work at a wide frequency band to obtain cross–autocorrelation functions. The considerations mentioned above show the necessity of developing and manufacturing a wide–band multi–channel receiver for IPS observations. Figure 1 shows the key diagram of a developed 6–channel receiver. Each channel is a direct–transform receiver with the bandwidth of 1 MHz supplemented with an analog multiplier, an integrator and a direct current amplifier. The multiplier can be used as a squarer. In this case each receiving channel will be a full power radiometer. And if two channels are attached to "North–South" and "West–East" antennas of UTR–2 radio telescope and the common multiplier is used, the signal, corresponding to the T–shaped radio telescope antenna pattern, is formed at the output. Each receiving channel contains input high–pass filter (f_0 = 18 MHz), input low–noise amplifier (KP = +7 dB), diode mixer with oscillator (18–32 MHz), low–pass filter (f_0 = 0.5 MHz), video amplifier (KP = +90 dB), multiplier, integrator (time constants 1, 0.1, 0.01 s) and direct current amplifier.

3 Some remarks on the practice of application of scattering theories for the interpretation of IPS data at extremely low frequencies

The scattering of meter and centimeter radio waves due to irregularities in the Solar wind has been studied in sufficient detail. This cannot be said about the scattering of decameter radio waves. Bovkoon and Zhouck [1981] and Braude et al. [1995] analyzed the scattering of decameter radio waves in the interplanetary medium on the basis of the phase screen method and of the radiation transfer equation. This method gives good results at centimeter wavelengths when the region of strong scattering has a small thickness. However, extremely low frequencies radio waves were effectively scattered by a thick layer of the interplanetary plasma that is impossible to consider as phase screen. Moreover, on large elongations the most scattering layers are located near the Earth, so the condition of applicability of the phase screen method is broken. At extremely low frequencies we have to consider diffraction effects and, in particular, to include amplitude fluctuations in the analysis. This allows to use Rytov's method [Rytov, 1937] and

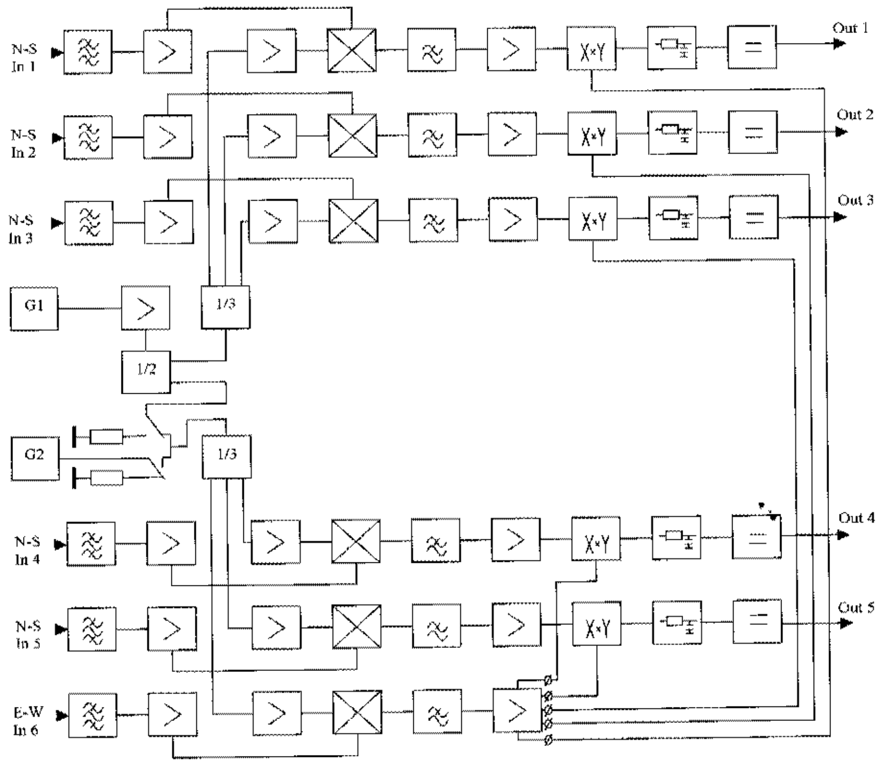

Figure 1: The key diagram of the developed 6–channel wide–band receiver.

the Feynman path–integral method [Frehlich, 1987; Kukushkin and Olyak, 1994] using the solution of the parabolic equations that is more preferable for the analysis of the mean–square and correlation function of radiation at the output of the plasma layer at extremely low frequencies. By the first approximation, these methods give identical expressions for the second moments. When obtaining dispersion of intensity fluctuations, the Feynman path–integral method allows to take the curvature of rays along a trajectory into account. The dispersion obtained with the help of the two methods will differ. This difference is unsignificant at large elongations and significant at small ones, especially in the supersaturated fluctuations case.

Until recently, using the Feynman path–integral method for the interpretation of IPS data was limited by the absence of powerful computers. Now this problem is solved. Authors have developed a model fitting method using expressions that are obtained by using the Feynman path–integral method for the description of extremely low frequencies waves scattering due to irregularities in the Solar wind.

4 Wide–band IPS observations

The 6–channel receiving complex has been developed and has passed tests in the structure of UTR–2. Testing scintillations observations of several compact sources have been carried out, and the scintillation spectra and autocorrelation functions have been built.

Figure 2 shows the result of the analysis of the scintillations data that were recorded on the

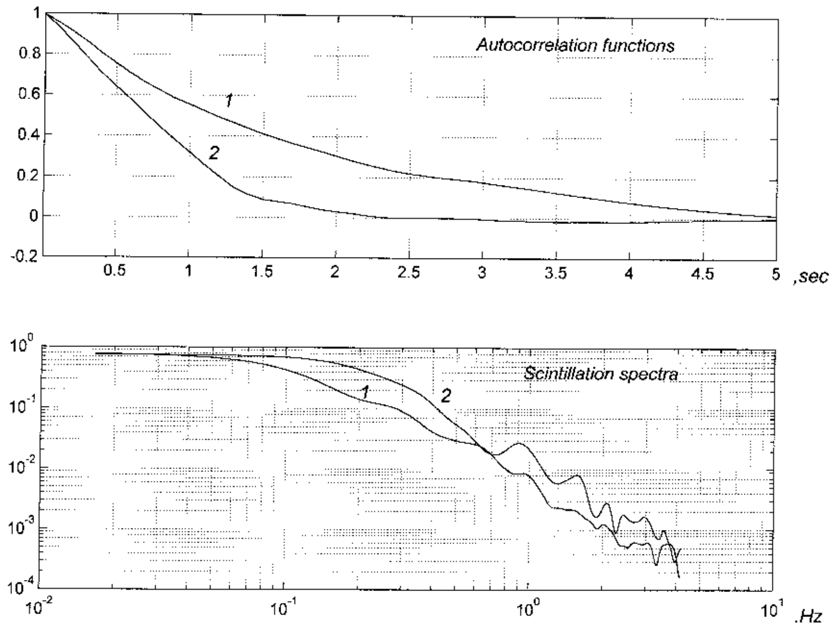

Figure 2: Autocorrelation functions and scintillations spectra of scintillations of radio source 3C380 (curve 1) and 3C254 (curve 2).

third channel output of the wide–band receiver. This channel corresponds to the central beam of the UTR–2 radio telescope. At the top part of the figure the autocorrelation functions of scintillations of radio sources 3C380 (curve 1) and 3C254 (curve 2) are shown. The first of them was observed at night when the level of interference was low and it was possible to average parts of the record. And the second was observed during day when the level of interference was high and there were only a few useful parts of record. The elongation of 3C380 was 130 degrees (weak scattering case) and of 3C254 it was 70 degrees (strong scattering case), so the autocorrelation function for 3C380 is wider than for 3C254 and the spectrum is narrower (shown at the bottom of Figure 2). It should be noted that the spectra obtained in the weak scattering case are essentially narrower than the ones obtained early by the other authors Bovkoon and Zhouck [1981] by using the UTR–2 radio telescope. We think this discrepancy can be explained by the following arguments: Namely, the authors Bovkoon and Zhouck [1981] used narrow–band receivers (10 kHz) and integrators with a great time constant (4 s), so they couldn't see the high frequency part of the scintillation spectra, even in the weak scattering case. As for the spectra in the strong scattering case that have been first obtained at extremely low frequencies, they were analyzed by using the low frequency waves scattering theory that is discussed above.

The devices and the methods developed in this work have shown a high efficiency, so they can be used to study the interplanetary medium at extremely low frequencies in future investigations.

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